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VSX J003909.7+611233: a new Slowly Pulsating B (SPB) star in Cassiopeia?

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We report the discovery of a new 13th magnitude variable star in Cassiopeia close to the variable KP Cas. Analysis of six days of intensive photometry shows a regular, near sinusoidal modulation with an amplitude of 0.024 mag and a period of 0.43815(31)d. Although its colour indicates a spectral type around F0 the star probably suffers up to 2–2.5 magnitudes of extinction, so could be an A- or B-type star. Given the period, the low amplitude, the shape of the lightcurve and the probable spectral type we consider it most likely to be a slowly pulsating B-type (SPB) star. The variable has been registered in the International Variable Star Index with the identifier VSX J003909.7+611233.

Discovery

During observation of the 2008 October superoutburst of KP Cassiopeia,¹ we observed variability in a nearby 13th magnitude star which had initially been chosen as a comparison star. We measured its position using *Astrometrica*² and USNO-B1.0 as RA 00h 39m 09.796±0.015s, Dec. +61° 12' 33.54±0.19" (J2000). Inspection of *Vizier*³ reveals catalogue entries at this position with the following identifiers: USNO-A2.0 1500-00686865; USNO-B1.0 1512-0023462, 2MASS J00390981+6112331 and GSC2.3 NALV008506. No previous record of its variability was found in GCVS⁴ or VSX⁵ and the star is not listed in *Simbad*.⁶ The 2MASS magnitudes are J= 12.61, H= 12.49, K= 12.43.⁷ We therefore believe the variability of this star is a new discovery and the variable has been registered in VSX with the identifier VSX J003909.7+611233. Figure 1 shows the field around KP Cas with the new variable marked.

Analysis

A log of 19 observing runs contributing to this analysis is given in Table 1. Details of the equipment used are given in ref. 1 and include a mixture of filtered and unfiltered systems. Images were dark-subtracted and flat-fielded and a measurement of the magnitude of the new variable was obtained from each of 8110 images using the same comparison stars as were used for KP Cas.¹ Heliocentric corrections were applied to all times of observation. The magnitude calibration of each observer's data was slightly different be-

cause of differences in the spectral responses of their equipment. A preliminary analysis of our data showed the amplitude of variation was 0.02–0.03 mag so it was clear that careful alignment of all observers' data in magnitude would be necessary to obtain an accurate measurement of the period and amplitude.

All lightcurves were inspected to locate the positions of maxima and minima. The time and magnitude at each extremum were obtained by a weighted second order polynomial fit to the lightcurve around the extremum. From these fitted maximum and minimum magnitudes, adjustments were applied to each run to bring the magnitudes of all runs into mutual alignment. The average size of these adjustments was 0.007 magnitudes. The resulting combined lightcurve over the 6-day interval 2008 October 27 to November 1 is shown in Figure 2. The Discrete Fourier Transform (DFT) power spectrum of the data is given in Figure 3 and this reveals a clear single periodic variation at $f=2.27$ c/d or $P=0.44$ days, with a full amplitude of 0.02 magnitudes.

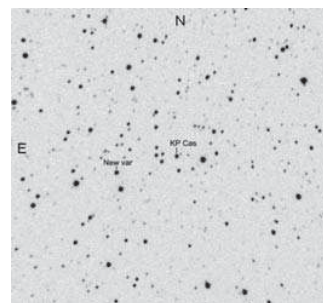


Figure 1. Location of the new variable close to KP Cas. V filtered image taken on 2008 October 27. Field 10'x10' (Boyd).

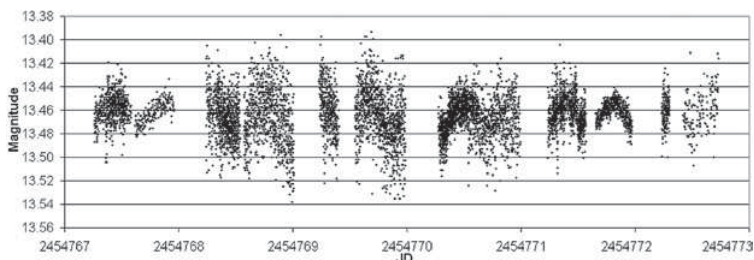


Figure 2. Combined lightcurve.

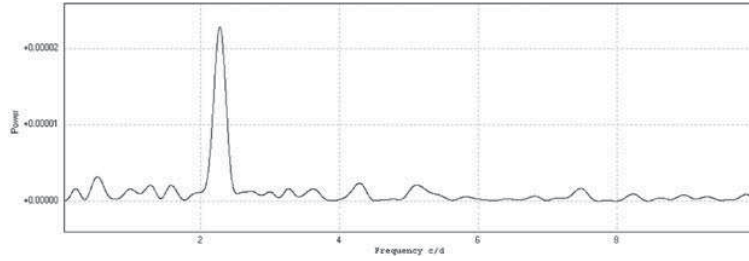


Figure 3. Discrete Fourier Transform power spectrum.

The period was refined in two stages. Firstly, cycle numbers were assigned to each maximum and minimum by inspection of the lightcurve. A weighted linear fit to these times gave the following linear ephemeris for the times of maximum light:

$$\text{HJD}_{(\text{max})} = 2454767.4648(45) + 0.43700(62) * E \quad [1]$$

and the observed minus calculated (O–C) times with respect to this ephemeris are shown in Figure 4. This gave an improved period estimate of 0.4370 days.

The internal scatter in the data from each observer ranged from 0.005 to 0.022 magnitudes according to the equipment used and the conditions prevailing at their observing site. This scatter was very consistent for a single observer from night to night. The datasets with larger scatter were first smoothed by averaging adjacent data points to make the internal errors consistent across the datasets. The combined datasets were then fitted with a Fourier series at the above period and also at twice this period, which would be appropriate for an eclipsing binary light curve, and in both cases small magnitude offsets were allowed for each dataset to find the best fit. The corresponding ephemerides are:

$$\text{HJD}_{(\text{max})} = 2454770.5218(36) + 0.43815(31) * E \quad [2]$$

$$\text{HJD}_{(\text{min})} = 2454770.7445(46) + 0.87602(61) * E \quad [3]$$

and the phase diagrams for these two solutions are shown in Figures 5 and 6. The data plotted in these figures are 5-point medians and the mean amplitudes are 0.024 and 0.021 magnitudes respectively. The lightcurve is basically sinusoidal but the minimum is rather pointed and the rise to maximum is distorted. Although these phased signals appear quite well

defined, their amplitude is small and caution needs to be exercised as the photometry is a combination of V-filtered and unfiltered data and the amplitude of the variable may change with wavelength.

Very little is known about the star although there are colours from 2MASS⁷ which give $J-H = 0.12$ and $H-K = 0.06$. Our measurements of the B–V and V–R colour indices give 0.39(1) and 0.23(1) respectively. All these values sug-

gest a spectral type near F0 if the star is unreddened, however, to give the observed V magnitude a main sequence star of this spectral type would lie at a distance of some 1500 parsecs. As the star lies within two degrees of the galactic plane there will be some reddening so the spectral type will be earlier than suggested by the colours. Measurements of the reddening in this direction suggest $E_{(B-V)} \sim 0.4$ for NGC 189⁸ which lies at 750 pc and $E_{(B-V)} \sim 0.6$ for the Cas OB4 association which lies at about 3 kpc.⁹ With $B-V = 0.39$ this amount of reddening means that the variable must be at least as early as spectral type A0 and might be as early as B2. The V magnitude, colours and reddening are most consistent with the variable lying at some distance, probably 2–3 kpc, which places it in the Perseus–Cassiopeia spiral arm. The 2MASS colours limit the visual extinction to $A_V < 2.5$ magnitudes so an earlier, more luminous star, say B0 would have to lie at several kpc and in this direction that seems unlikely.

Given the range of possible spectral types this star could, on the face of it, be almost any of the low-amplitude variable stars on the upper main sequence (see Degroote *et al.*¹⁰ for recent references). If the star is a very early B-type then it may be a beta (β) Cephei variable but at 0.44 days the period would be extremely long¹¹ and from the previous discussion the luminosity would be at the upper limit of acceptability. The Slowly Pulsating B-type (SPB) stars occupy the range from B2–B9 and although these typically have periods of 1–4 days this variable does lie within the short-period limit.¹² If the star is a chemically peculiar Bp or Ap star then low amplitude variations could be produced by rotation but again the periods of these variables are typically a few days.¹³

Cooler pulsating variables like the gamma (γ) Doradus¹⁴ and delta (δ) Scuti¹⁵ variables are generally F-type stars and can probably be excluded on colour and luminosity grounds. The δ Scuti variables also have much shorter periods. Finally, the variable may be an eclipsing binary or ellipsoidal

Table 1. Log of observing runs

Start time (JD)	Duration (hrs)	Filter	Observer
2454767.26039	7.70	V	Boyd
2454767.36072	4.10	C	Shears
2454767.61938	8.13	V	Julian
2454768.24024	7.14	C	Shears
2454768.26340	6.40	C	Staels
2454768.57255	10.48	V	Koff
2454769.22919	4.17	C	dePonthiere
2454769.23649	3.67	C	Staels
2454769.54403	10.60	V	Koff
2454769.60627	8.44	V	Julian
2454770.27623	8.24	C	Boyd
2454770.28947	5.77	C	Shears
2454770.53278	11.01	V	Koff
2454770.60228	8.54	V	Julian
2454771.23582	7.97	C	Boyd
2454771.26962	7.00	C	Shears
2454771.65566	7.56	C	Krajci
2454772.23536	1.56	C	Shears
2454772.42193	7.35	C	dePonthiere

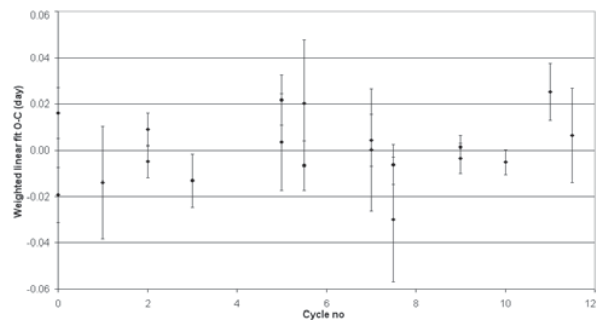


Figure 4. O–C diagram with respect to the linear ephemeris in equation (1).

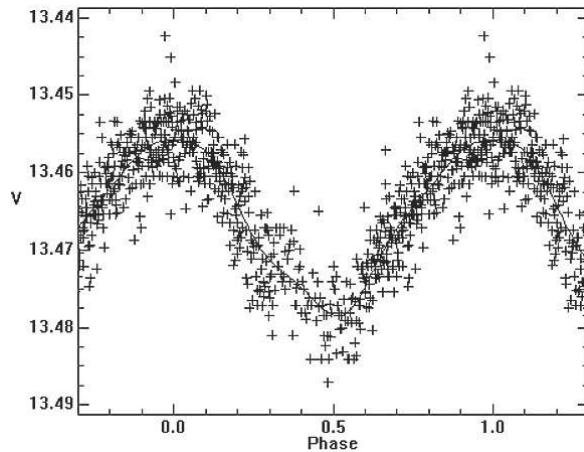


Figure 5. Averaged phase diagram for a period of 0.43815d using equation (2).

variable seen at low inclination. Given the period and likely spectral type the circumstances would have to be very specific to produce such a low-amplitude variation.

On the available evidence, there is little to choose between the photometric solutions with one or two minima. Since the two halves of the longer period are not significantly different in shape or amplitude this solution does not recommend itself, but at the same time it cannot be excluded. If it were an eclipsing binary it is not clear what could cause similar distortions in both halves of the lightcurve. Given the shape of the lightcurve the most likely interpretation is a pulsating variable and the probable spectral type suggests an SPB star. These variables frequently show multiple periods but no other significant periods have been found in the data analysed here. Any other periods must have amplitudes below 0.005 magnitudes, although it is conceivable that larger variations could show up in longer runs of data

Conclusion

A new variable star has been found in the field of KP Cas with an amplitude of 0.024 magnitude and a period of 0.43815(31) days. It is probably reddened by about half a magnitude and most likely lies in or near the Perseus – Cassiopeia spiral arm. The shape of the lightcurve and the probable spectral type suggests it is an SPB star.

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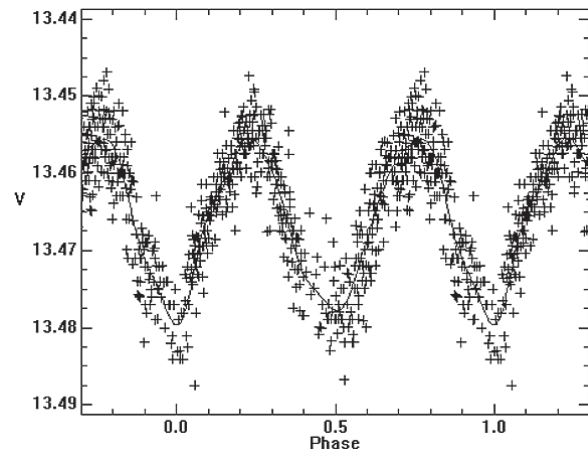


Figure 6. Averaged phase diagram for a period of 0.87602d using equation (3).

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